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Towards Industry 4.0 | A case study of BIM Deployment in Ornamental Stones Sector

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Abstract

The transition witnessed from the Third to the Fourth Industrial Age leads to the emergence of paradigms such as BIM, seeking efficiency in Architecture, Engineering and Construction (AEC) through a global approach and procurement oriented towards standardized products and I4.0, where production comes to be supported by Cyber-Physical Systems (CPS). Integrated in the AEC supply chain, the ornamental stone sector shows Portugal to be the eighth country in OS trade worldwide, and the second per capita, with its competitiveness coming from customization BIM represents threats for its business sustainability. Supported by the Service Science, the main objective of this research is to conceptualize an empirical framework, which, when applied to a sample of Ornamental Stone companies, allows a conclusive answer how to keep their competitive advantage of products customization in BIM-standardized procurement environment. By monitoring the entire sequence of events, it was found that the Ornamental Stone companies can retain their main current competitive advantage of customizing their products, which leads us to conclude that Industry 4.0 technologies, appears to respond positively to threat raised from BIM procurement.

Keywords: Ornamental Stones; AEC; Innovation Outcomes; Optimization; Construction Industry; Natural Resources.

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1. Introduction

Integrated in the Architecture, Engineering and Construction Supply Chain (AECSC) [1], despite the decline in global demand for construction materials since the sub-prime crisis in 2008 [2–6], the Portuguese OS sector has recorded an average annual growth of 4.6% in exports between 2006 and 2018 [7]. Moreover, it has been identified that in a group of companies, a continuous improvement in sales, exports, skills admission, environmental care and other indicators have been substantially higher than the sector averages since 2005 [4]. The excellent performance of this group of companies [6] represents good examples that others must follow, and therefore, they are members of the Cluster Portugal Mineral Resources (CPMR) [8].

1.1 Procurement shift in the AEC Supply Chain

Referred to as inefficient by some Governments [9], practitioners [10] and academics [11], the current procurement model in the AECSC generates avoidable wastes [12], which are reflected in construction and maintenance costs, construction time and ecological footprint, from the beginning of the building project up to the end of its life cycle [7,13]. To reduce this wastes, some Governments [14]are currently supporting the popularization of the Building Information Modelling (BIM) technology in the AECSC. In the BIM context, the traditional procurement model shifts to "BIM procurement" [9], which will occur during the building design phase [15]. In a ISO Standard digital format [16] and publicly tendered on the Internet [17], the construction products and materials are pre-designed (standardised) and made available to BIM workstation operators by their providers [18], which in practical terms, means that the procurement task will be anticipated to the building design phase (project phase) [19]. Paradoxically, contrary to the official objectives that support the generalisation of BIM in IC [9,20] from our own experience as consumers, we can observe, in many sectors, the trend in demand towards customised goods. This trend, combined with increasing market volatility, has forced industry to search for new forms of production, based on digital technologies [21]. This tendency to incorporate digital technologies as a way to respond to increasingly customised demand has led governments [22], practitioners [23] and academics [24] to consider that a new Industrial Age is starting now, the fourth one, characterised by Digital Production combined with the Internet [25] and popularised by the term "Industry 4.0" (I4.0), [26,27]. To operate in I4.0 mode, the production must be supported by Cyber-Physical Systems (CPS), in which products, machines and customers, connected to the Internet, interact before, during and after the production process [28,29]. In this context, we may consider that the I4.0 operation mode will allow OS companies, particularly the members of CPRM, to respond positively to threats arising from BIM procurement in the AECSC. The researches carried out in the sector in recent years leads to the conclusion that the positive response of Portuguese OS companies appears to be related to the incorporation of modern practices and technologies in their production, which allowed them to offer the custom-made market products [30]. In the BIM context, procurement in the AECSC will tend to be orientated towards standard products. Referred to as companies following Current Best Practices (CBP) in the OS sector [8] and operating in the international market, the CPMR companies are most exposed to global competition, and may consequently be the first to feel the threat resulting from the shift to BIM procurement in the supply chain [31]. From these threats, the following Research Question (RQ) arises: will Industry 4.0 operations, in the context of BIM procurement, allow Ornamental Stone companies to retain their main current competitive advantage of customizing their products?

In addition to the empirical contributions from the answer to this RQ to OS companies, a scientific approach to the co-creation of value between the resources of the I4.0 providers (digital providers) and BIM customers (digital engineering customers) may also contribute to mitigate the investment risks associated with the very early stages of digital production, in relation to more environmentally friendly consumption and more sustainable industry [32]. Supported by the RQ, the main objective of this research is to conceptualize an empirical framework, which, when applied to a sample of Ornamental Stone companies [33], allows a conclusive answer about the customization of their products, in the context of BIM procurement environment.

2. Industry 4.0 Technologies

As we draw closer to the present day, the XXI century, we see the ability of industry to produce customized goods with a shorter and shorter lifespan [34]. This intense increase in the variability of industry's capacity [35] and consequent increased market volatility has led many observers to believe Industry is on the cusp of its Fourth Technological Paradigm [36], driven by the digitization of production processes combined with widespread use of the Internet [25]. The term "Industry 4.0" has been popularized since 2011 [37] when the German Government created a National Initiative with this designation [38] to ensure that the German industrial sector would maintain its leading position in the coming decades [39]. From the early stages, this official German Initiative [21] involved Chancellor Merkel and thereby all Ministries, Universities, Research Centers, large companies, unions and countless other strategic partners in the country, in the belief that Germany's industrial leadership can only be maintained if the country takes the lead as a user and global implementer of the technologies of the "Internet Smart Factories" generation [40]. Therefore, The term Industry 4.0 refers to the combination and integration of digital technologies such as Advanced Robotics [41], Artificial Intelligence [42], sensors [43], Cloud Computing [41], IoT [28], analysis, and sorting of Big Data [44], Augmented Reality [45], Additive Production [46]and Mobile Devices [47], among other digital technologies, into an interoperable and shareable global value chain, regardless of geographical space.

3. Literature Review- Service Science

As the Body of Knowledge was consolidated, the designation Service Science (S-S) [48], has been used as a diminutive or as a substitute for the Service Science, Management, and Engineering designation [49]. According to the main precursors [50], from 2008 S-S became a new scientific area, available to develop the skills needed for economic activity based on service. By abandoning the traditional perspective [51,52], where products and services are understood separately, Service Science adopted the concept of service exchange [53] and thus, service and service systems have become the objects of study for this new scientific area, in the sense of its development and improvement in order to create value and innovation for an Ecologically Sustainable and better World [49]. By adopting the vocabulary and philosophy of Service-Dominant Logic [54,55], the field of application of S-S went far beyond the activities of services, applying its scientific methodologies to all types of economic activities related to the production of tangible and intangible goods [56].

4. Methodology

Guided by the pragmatist paradigm [57], the fundamental challenge of this research is to describe, provide the foundations for, and apply to an empirical case, a framework conceptualized through the Service Science, making it possible to describe and compare the value creation interactions [58] in a sample of ornamental stone companies belonging to the CPMR (CPMR-OS) when they evolve their operations from the Current Best Practices (CBP) mode to the I4.0 mode.

4.1 Data Collection Procedures

The procedure of selecting orders to follow up and data collecting will be by convenience as was the selection of companies to belong to the sample group, since they have to be aligned with CPMR-OS companies' core business, where cut-to-size stone covering is one of the main products [3,59–62]. The data acquisition process will be continuous like in a movie, and throughout the service process, the observer (researcher) will observe and collect the data in real-time, respecting the previously described procedures.

4.2 The Population and sample

From the researches carried out in recent years and related to the Portuguese Ornamental Stone sector [3–6,60–62], we can infer that the group of CPMR-OS Companies can be considered to represent CBP within the Portuguese Stone sector. In this connection, CPMR-OS being formed of front-line OS companies operating in the global market, we may consider that at the sectoral level, on the one hand, these companies will be the first to feel the threats of BIM procurement, but on the other hand, maybe better prepared to adapt their operations to the digital processes resulting from I4.0. Therefore, this population will be studied in this research, and we will apply the empirical framework to a representative sample of this population. Given the specificity of this study, the sample must be of convenience. The companies must be selected intentionally from the population of OS companies, members of the CPMR, since the orders to use in this study must be real and the data observed in real-time as the resources of the stakeholders involved co-create value throughout the service process.

4.3 Service Blueprinting Methodological Tool

The *service blueprinting* (S-Bprint) is a methodological tool recommended by S-S to map the shared access to s-system resources [63]. Starting from the original format as introduced by Kingman-Brundage (1989) the S-Bprint format to be adopted as part of this framework must avoid theoretical causes and organizational pitfalls during its usage [64]. Only suitably adapted can it be useful to managers in their decisions regarding their organizations' sustainable growth [64], especially allowing comparison of the different service innovation structures of the Fourth Industrial Age [65].

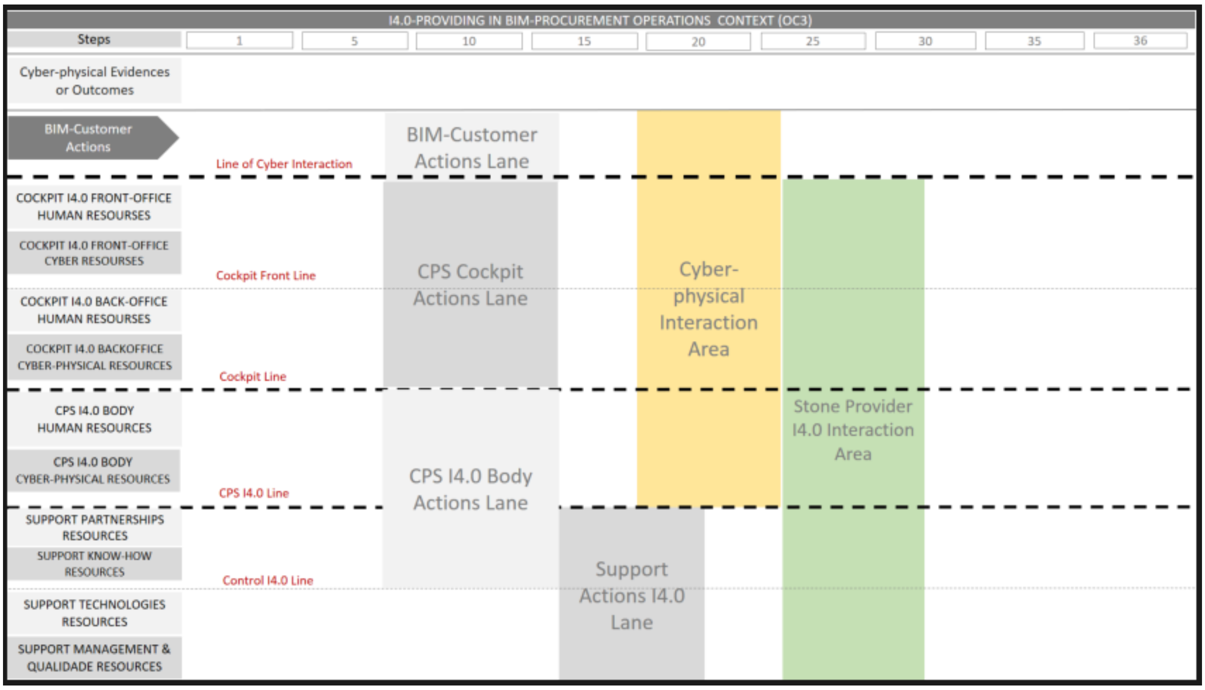

Figure 4.1: Service Blueprinting Format for I4.0-Providing in BIM-Procurement Operation Context

This new S-Bprint format (Figure 4-2), keeps the separation of service interactions in individualized processes by horizontally represented steps [66], where each individual component (activity) belongs to a different lane, ordered vertically with each one representing, as in the Shostack model [67], a level of proximity to the customer. The higher in the map the lane of the provider's resources involved in the actions, the closer the level of interaction with the customer stakeholder.

4.4 ISPAR Methodological Tool

In every step of the service process [68], once the value proposition is made by one stakeholder, understanding depends on the perception of the value of the other stakeholder's resources, and its acceptance will depend on the combination of the different resources. If the proposal is refused, it means that no value results from the proposal.

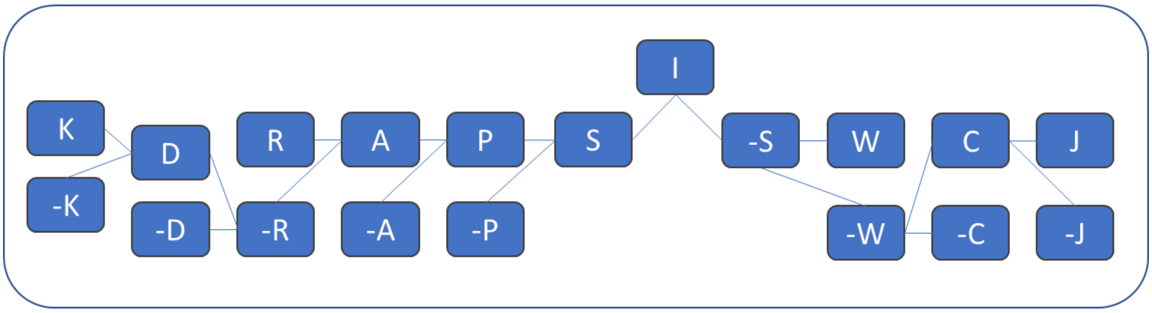

Figure 4.2: ISPAR Outcomes

The empirical framework uses the *Interact Serve Propose Agree Realize* (ISPAR) tool to classify the Outcome of value propositions, in terms of ten different possible SO (Figure 4-2) - (i) the value is performed as proposed; (ii) the proposal is not perceived; (iii) the proposal is not accepted; (iv) value is not realized but does not generate a dispute; (v) disputes are settled by agreement between the parties; (vi) disputes are not resolved by agreement between the parties; (vii) an interaction is, after all, a non-service interaction since it does not create value but is nonetheless peaceful for all, (viii) non-service interaction and is interpreted as illegal and may be a matter for the courts, (ix) the non-service interaction is interpreted as unlawful (x) non-service interaction is unwanted but the legal authorities do not confirm it as illegal or the culprit is not identified.

5. Empirical Framework application

By using the Pragmatist Worldview guidelines and Parallel Convergent Mixed Methodology supported by Service Science Theory, the purpose is to apply the empirical framework, as conceptualized, to a sample of OS companies, members of the CPMR.

5.1 Operations Context 1 (OC1): CBP-Providing in CAD-Procurement

For the data collection in CBP-Providing in CAD-Procurement (OC1), the monitoring of each order was carried out in a different company, within the sample, from the negotiation step where the customer introduced the CAD project and production in CBP operations until the products are delivered to the right customer.

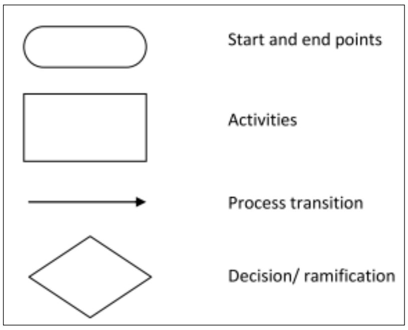

Figure 5.1: Service Blueprinting Symbol System

After mapping the CBP-Provider resources through the S-Bprint in different interaction lanes, the activities of these resources were mapped along the service process, executed simultaneously with the data collection resulting from value interactions. In S-Bprint map s, access to resources will be referenced by unidirectional or bidirectional arrows and their activities by rectangles (Figure 5-2). During the orders' execution in OC1, at each step of the service process SO evaluation was carried out by the ISPAR. As conceptualized and detailed, the empirical framework application assumes that the service process is sub-divided into 36 main steps. In the steps where the SO resulting from interactions has not been normative, there is a need to innovate in this step, and thus, the process returns to previous steps and can even definitely stop the service process or lead to disputes, a situation, however, not verified in the OC1 under analysis. Searching for similar orders in the sample OS companies was the way to ensure the results could be comparable. The orders found were placed by international clients and cut-to-size facade, using limestone of 30mm thickness, *fischer* anchoring and for different clients.

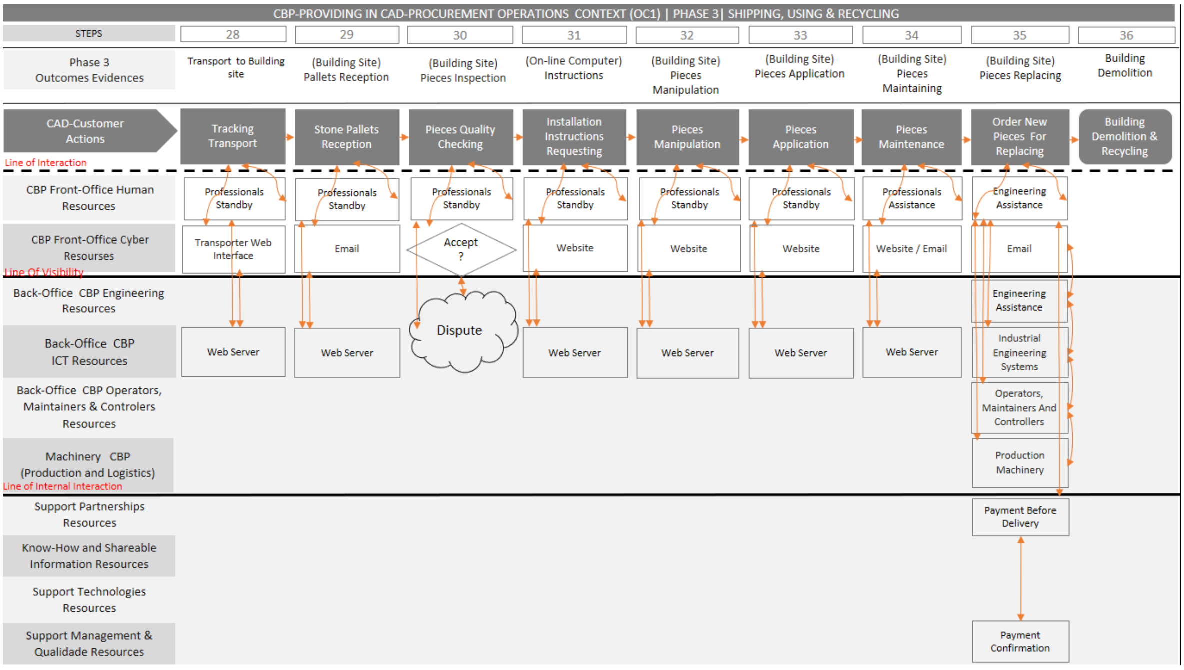

Figure 5.2: OC1 (CBP-Providing in CAD-procurement) | Resources Activities, Access Rights and Interaction Outcomes Service-Blueprinting Mapping | Phase 2 (steps 28-36)

In this way, service process analyses were concluded in CBP-Providing in the CAD-Procurement Context (OC1), and this was also the end of data collection for this research, in all cases the ISPAR Outcome being (SO = A). During these steps, the data collection related to steps 28-36 in OC1 operations mode was concluded successfully (Figure 5-2).

5.2 Operations Context 2 (OC2): CBP-Providing in BIM-Procurement

In CBP-Providing in BIM-Procurement operation mode (OC2), the supplier companies (CBP-OS-Providers) will be the same as in OC1. However, as the orders to be studied are new, the customers will be different because in this case, it was necessary to ensure that the customer was a BIM user instead of a CAD user, and thus become a BIM-Customer. On the other hand, by keeping the operations in CBP mode, the resources of the CBP-OS-Provider, as in OC1 operations mode, will be placed as before in lanes, below the line of interaction of the S-Bprint service process mapping. The process of collecting data on the stakeholders involved in the CBP-Providing in BIM-Procurement (OC2) context, as represented in (Figure 5-3), was started in all the companies in the sample, with the "BIM Workstation & Internet Connection" action (step 1).

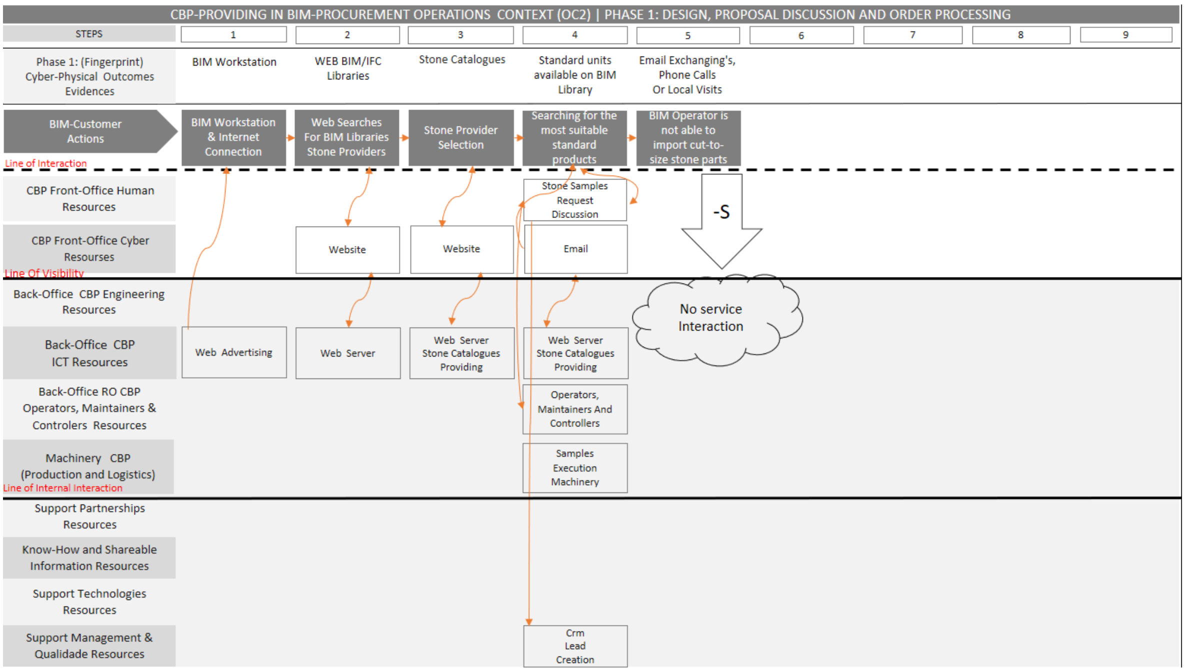

Figure 5.3: OC2 (CBP-Providing in BIM-procurement) | Resources Activities, Access Rights and Interaction Outcomes Service-Blueprinting Mapping | Phase 1 (steps 1-9)

Action 2 "Web Searches for BIM Libraries Stone Providers" meant that, somewhere in the world, BIM operators were using their workstations to search for BIM Libraries on the web where there are products in stone (step 2). As in OC1, in the first two steps, the CBP-OS-Provider suppliers' propositions were limited to promotion actions and so far, not related to the BIM operator's initiatives. In step 3, BIM operators during the "Stone Provider Selection" action have found BIM web libraries with stone products, with attractive examples provided by the suppliers, which led the BIM operators to download the catalogues in the "Stone Provider Selection" action. This gave the first normative outcome. We may consider that, as in the previous context, also in OC2 the catalogues must have transmitted a positive image of the suppliers, otherwise the BIM-Customers would not have gone to the next step. Observing the S-Bprint mapping, to date, no non-normative outcomes are identified in any of the companies in the sample. Simultaneously with downloading the catalogues, the CRM recorded this BIM-Customer as a potential customer searching for products in stone, thus automatically generating a lead in the Customer Relations Management (CRM) server. The flow from step 3 to step 4, where the outcome of the "Direct Connection to Stone Provider" action was dependent on how BIM-Customers appreciated the electronic catalogues, was (SO = S) in all monitored cases. In step 4, "Searching for the most suitable standard products", all the potential BIM-Customers wanted IFC products in stone, as placed in the BIM- Libraries, to fit (cut-to-size) the real geometries of their projects. However, because the BIM-WEB-Libraries only contained standardized products, this resulted in non-normative ISPAR Outcomes (SO = -S) in all monitored cases in step 5. These (-S) Outcomes had stopped the service process in all the cases, and thus it was not possible for BIM-Customers to buy cut-to-size products from the CBP-OS-Providers through the BIM-WEB-Libraries, and so immediately lost interest in pursuing the acquisition process, claiming that in standard mode they would go to search for alternative materials instead of natural stone [69]. In fact, in standard product mode, price becomes one of the main factors in the purchasing decision in the AECSC, where CPMR-OS companies find it difficult to compete against their Asian competitors and ceramic materials, as detailed in Chapter 2 of this thesis. It was this discrepancy between the competitiveness of the CPMR-OS companies and the BIM-Procurement that resulted in (SO = - S) in all cases and in one of the cases the Outcome was even worse (SO = - W) [50], and thus, the service process did not go through (Figure C.5, Appendix C). This situation was somewhat predictable since one of the purposes of official support for BIM-Procurement is precisely to guide the AECSC to standardized products [70]. Faced with the impossibility of purchasing cut-to-size products, BIM-Customers would tend to buy lower-priced alternative products, and be no longer interested in purchasing standard stone products, turning instead to ceramic materials where homogeneity is guaranteed. Predicting that this problem might happen, the sample CPMR-OS companies agreed to prepare an alternative which was ready to be proposed to all five BIM-Customers in OC2 operations mode, with whom contact had not yet been broken. As soon as the BIM-Customers were contacted one by one, it was proposed that they agree to link their BIM platforms to Cockpit of the "prototype mini-factory I4.0", as presented in Chapter 4, i.e., tracking of the orders would become the I4.0 digital mode of operations, and the data collected are presented in the next section. It was in this context that all BIM-Customers were contacted one by one, inviting them to connect their BIM-Workstations to the Cockpit of the "mini-factory I4.0 prototype", as introduced in Chapter 4, that is, tracking of the orders would pass to I4.0 digital operations, and the data collected, and resources activities will be presented in the next section.

5.3 Operations Context 3 (OC3): I4.0-Providing in BIM-Procurement

At the time orders were selected to be executed in BIM procurement context, it was anticipated that the CBP mode of operations would generate a non-normative OS. Once the I4.0-Provider resources were formatted in the different S-Bprint interaction lanes, the activities of these resources were mapped throughout the service process, recording the value creation interactions between BIM-Customer and I4.0-OS-Provider (OC3) as well as the access rights to the resources, referenced by unidirectional or bidirectional arrows, as in the previous contexts OC1 and OC2.

5.4 Operations Context OC3: Phase 1 (steps 1 to 9)

The service process mapping and data collection began in the stakeholders involved in the five orders in I4.0-Providing in BIM-Procurement Context (OC3), where, as represented in the S-Bprint map (Figure 5-3), the first action of the service is "BIM Workstation & Internet Connection" (step 1), which means that the five BIM operators were using their BIM workstations connected to the Internet and searching for BIM-WEB-Libraries, looking for stone products for their projects (step 2). In step 3, the “Stone Provider Selection” action, the BIM-Operators will have found BIM-WEB-libraries with stone products and decided to download high-resolution catalogues with technical information though the Cockpit, in the "Stone Provider Selection" action, which resulted in normative outcomes (SO = S).

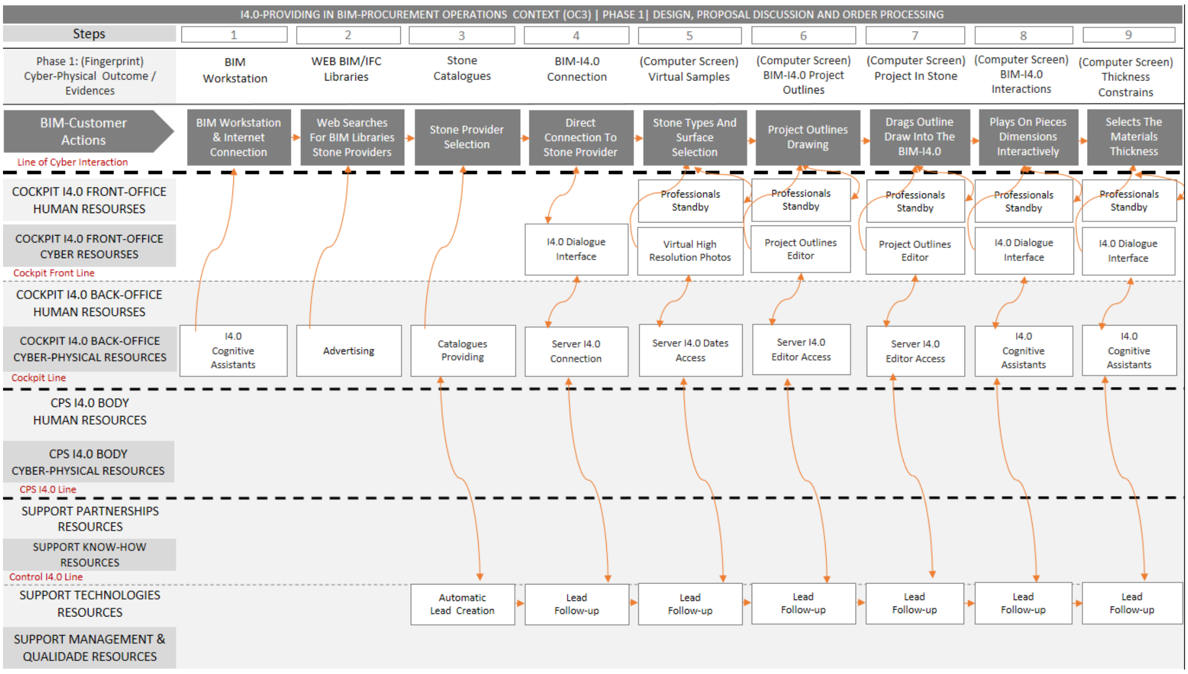

Figure 5.4: (I4.0-Providing in BIM-procurement) | Resources Activities, Access Rights and interaction Outcomes and Mapping | Phase 1 (steps 1-9)

To move from step 3, whose action is “Direct Connection to Stone Provider” to the next step, meant that BIM-Customers positively appreciated the electronic catalogues available, thus generating (SO = S). Connected to I4.0-OS-Providers Cockpit in the "Server Industry 4.0 RO" action (step 4), (Figure 5-4) BIM operators start the interactive dialogue process with the Cockpit, in particular with its I4.0 Dialogue Interface resource, while CRM follows up these potential customers. Once the remote connection of the BIM-Cockpit resources is guaranteed, the BIM operators now have all the I4.0-OS-Providers’ resources available as if they were their own resources. This communication facility made them very pleased. Additionally, it was verified that the modern mode of "opening" up production to clients generates high levels of trust (Contract Compliance = U), the level of reputation of the brand, and raises the potential quality of products. In turn, suppliers appreciated customer happiness, while for the competition, it became more difficult to access the customer-supplier interactions as they were carried out remotely and without interruptions. It was therefore in this interactive dialogue that BIM operators performed the "Stone Types and Surface Selection" actions, followed by step 5 in which the Cockpit provided high-resolution photos of the different types of finishes in the catalogue of materials. Simultaneously, the BIM screens showed there were professionals on the Provider side, available to assist if necessary. It was also this collaborative environment [71] of a close customer-supplier relationship that had facilitated the transition from step 4 to step 5 through the step outcome (SO = S). The availability of "Virtual Samples" (step 5) in I4.0 mode meant that if customers wanted to get real specific samples, they could monitor the process in real-time and in an interactive way. It was in this context that suppliers, after a virtual evaluation by the customers, sent the physical samples executed by normal (less cost) freight, since the service process was not pending the reception of these by the client. This avoided waiting several days and increased customer satisfaction, as well as technical concerns such as or safety. Data related to the Authorities and Competition stakeholders, up to this step (step 5), were like those in OC1 mode. Providers were happy since the customers were happy. Once guaranteed (SO = S) in step 5, the process moves to the "Project Outlines Drawing" action (step 6), where BIM-Workstations automatically provide the Cockpit (step 7) with the layout of the façade to be covered in stone, without any time wasted in this step. No emails or phone calls were needed, as happened in OC1. Using virtual samples of the raw material types including their finishing's, the BIM modellers performed the "Plays on Pieces Dimensions Interactively" action (step 8), where they could visualize the total space to cover, changing the base unit dimension of each shape element interactively. At this stage, much of the Cockpit's resources, both human and technological, were involved. Being a task entirely led by the criteria of the BIM-Operator, without any restriction in-unit geometries and with the flaming lines oriented according to their criteria, satisfaction was observed, as well as confidence in the quality, the seriousness of the supplier and the product's technical characteristics. After step 8 was over, the process moved to the "Selects the Materials Thickness" action (step 9), where BIM operators could choose the thickness of the stone parts, after which they were invited to select the "Automatic Cut-to-size Option" (step 10). It was confirmed that until this step 9 of the service process, the deadline for product delivery had not yet become a concern for BIM-Customers or the sample I4.0-OS-Providers, probably because the information provided through the Cockpit, showed the estimated delivery time clearly enough to everybody. Here, we finished collecting data related to the first nine steps of the service process.

5.5 Operations Context OC3: Phase 1 (steps 10 to 18)

The step 10 was critical because it was here the Cockpit automatically "adjusts" the parts to the limits of the available facade, with formats as close as possible to the base dimension chosen by the BIM modellers. It is also in this step (step 10) that, in OC3 mode, the products had been converted to the customer's needs for standard products, thus cleverly satisfying the requirements of the BIM procurement, that is, the Cockpit sets out from the products customized by the BIM modeller, remotely, and makes them available to BIM as if they were standard, thus solving one of the main issues resulting from BIM procurement.

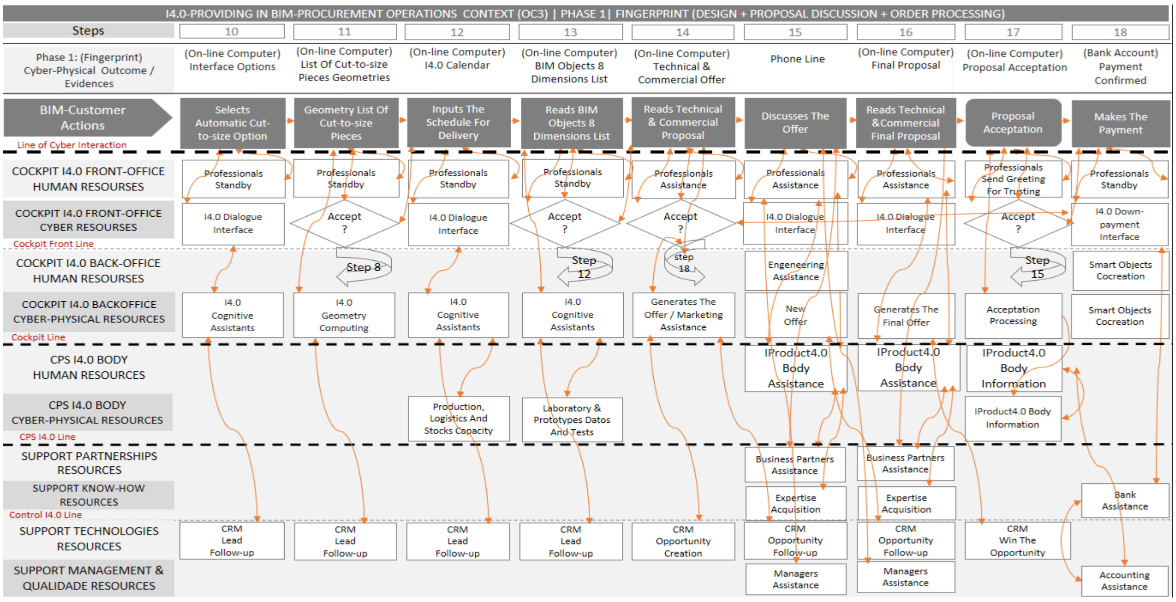

Figure 5.5: (I4.0-Providing in BIM-procurement) | Resources Activities, Access Rights and Interaction

Outcomes and Mapping | Phase 1 (steps 10-18)

In the "Geometry List of Cut-to-Size Pieces" action (step 11), the Cockpit directly put the question to the BIM operators - whether or not they should accept, from a technical point of view, the proposed parts list, resulting in (SO=P) in step 10 (Figure 5-5). Given this question asked by the Cockpit to the BIM modeller, the resulting outcome (step 11) might be "A". In cases where customers accepted, the process moved to step 12, and in the cases of (SO = -A), the process returned to step 8. On the first or second attempts, (SO = A) was confirmed in all monitored cases, therefore normative, allowing the service process to proceed to the next step, the “Schedule for Delivery” action (step 12), that is, knowing the period (5D-BIM) in which the customer wishes to receive the stone products. Having received this input from the BIM operators, the Cockpit automatically generated the complete parts list with their eight BIM dimensions (step 13) - geometries (3D), prices (4D), delivery time (5D), footprint (6D), maintenance (7D) and safety (8D). Additionally, according to the ISPAR methodological tool, in step 13 the stakeholders face an interaction whose Outcome for most of the sample OS companies was (SO = - A) at the first attempt, that is, at the second attempt clients accepted almost all the customer conditions and thus, the system moved to step 14. In one case, however, (SO = - A) was found, and thus the service process regressed to step 12, but at the second attempt, (SO = A) was found in step 13, joining the remaining cases under study. When accepting the parts list and respective BIM specifications, the Cockpit immediately made a value proposition (step 14) and, similar to step 10, also in step 13 if (SO = - A) was verified. At the outset, it would not have been due to the technical incapacity of the I4.0 supplier, but perhaps due to the customer’s personal choice. Additionally, in step 13, according to the ISPAR methodological tool, we were dealing with an interaction whose Outcome in most of the sample companies was (SO = A) at the first attempt, and thus the service process moved to step 14. In one monitored case, however, (SO = - A) was the outcome, and thus, the service process returned to step 12, but at the second attempt, (SO = A) was found in step 13, this Company joining the remaining cases under study. When accepting the parts list and respective BIM specifications, the Cockpit immediately placed the value proposition with the BIM-Operator (step 14). As in step 10, also in step 13 if (SO = - A) was found, it would not have been due to the I4.0-Provider’s technical incapacity, but just to customer choice. From the commercial point of view, in step 14, a sequence of decisive steps began, since here the customers would decide whether to place the order or not. In step 14, we were faced with a value proposition, which for CRM was treated as an "opportunity" and whose Outcome would be "A" if customers accepted it and in that case, the system would progress to step 18. To avoid the potential situation of (SO = - A), providers did not give up on "forcing" the service process to move to step 15, so all I4.0-OS company’s resources were called upon to provide assistance, including the Managing Directors, to adapt and discuss the proposals with clients, including meetings whenever necessary. In step 16, BIM-Customers evaluate the value proposition in the "Reads the Technical & Commercial Final Proposal" action. After step 17, if the Outcomes were "A", it would mean the proposals were accepted and the service process would move to step 18. In cases where at the first attempt the outcome was (SO = - A), suppliers interacted with the customer and did not let the opportunity disappear, returning to step 15 until they won the order. Thus, in all cases, the process moved to step 18, in which BIM-Customers confirmed payment in the "Makes the Payment" action (step 18). After confirmation of payment, Phase 1 of the co-creation process in which the Fingerprint of the objects was created, is over. At this step of the process, all parts were now available as an eight dimensions Fingerprint and ready to be transformed into Smart-Objects, through interactions between the Cockpit and the CPS-Body, during the transition from step 18 to step 19 and all the orders monitored had resulted in (SO = A) in step 17. During all these steps, the data collection related to steps 9-18 in OC3 operations mode was concluded successfully.

5.6 Operations Context OC3: Phase 2 (steps 19 to 27)

The Phase 2 is related to production of the order, that is, in the I4.0-Providing in BIM-Procurement context is the phase in which the Cockpit becomes available to transform the Smart Objects, resulting from the Fingerprint, into physical products. This phase of the process (Figure 5-6) also comprises nine main steps, where step 19 corresponds to the preparation of the stone blocks. In OC3, this operation was monitored remotely (online) by the BIM-Customers' "Tracking Blocks Execution" action, as well as in step 20, corresponding to transformation of the blocks into slabs. We may thus consider that up to step 20 of the OC3 production process, at the shop floor level everything remained like OC1. Only the customer level became different since the customers were able to follow the process progress in real-time. However, from step 20 onwards the productive operations change substantially in digital operations mode I4.0 when compared to the CBP operations mode (OC1).

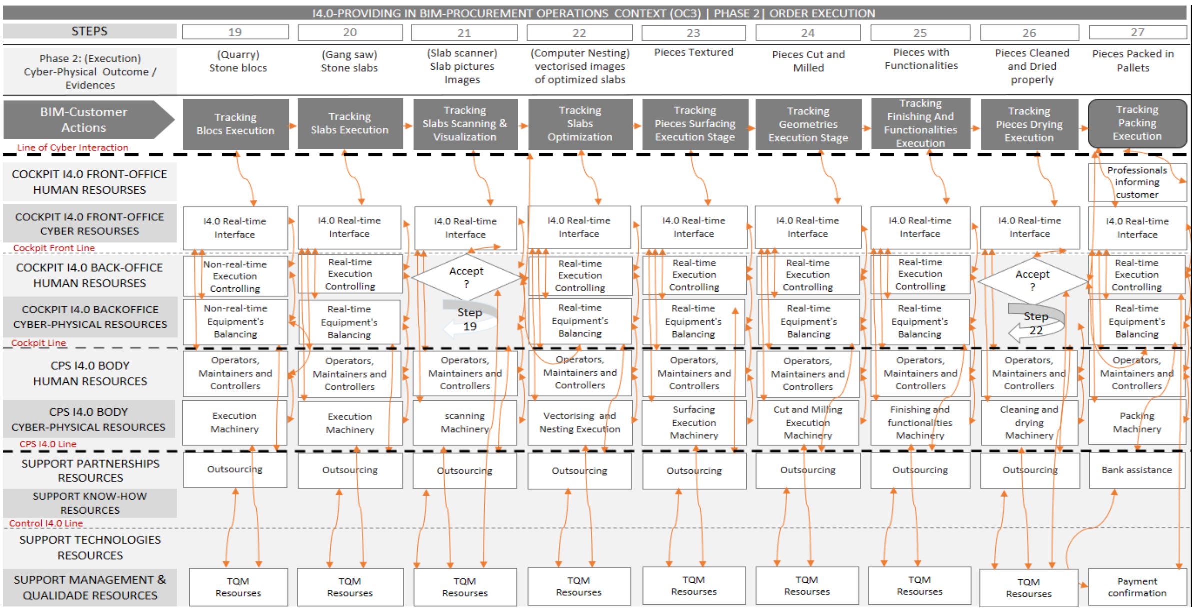

Figure 5.5: (I4.0-Providing in BIM-procurement) | Resources Activities, Access Rights and Interaction Outcomes and Mapping | Phase 1 (steps 19-27)

If, on the one hand, in the CBP production mode (OC1), for example, the "Surfacing operations" (step 20) evidence meant flaming the full slab surface, in I4.0 production mode this evidence meant that the stone slabs had been scanned first, vectorized and QR coded, a real-time operation remotely monitored by the BIM-Customer. For the ISPAR tool (step 21) we were faced with the realization or not of value creation, whose SO would be (R) if the customers accepted the raw materials and in that case, the service process would progress to step 22 or, if the SO became (-R), the process would return to step 19, to avoid disputes. Through the observations, the outcomes from step 21 were (SO = R) in all the cases studied, so the service process moved to step 22, in which optimizations of raw materials were performed, using artificial intelligence algorithms, in virtual mode, from the vectorizations as performed in step 21. However, the physical raw materials had been kept at this step in the warehouse, which meant a reduction of the internal logistics operations. After reading the slab QR code (step 23), only the useful area of the raw materials was flamed, according to the optimization previously performed by the Cockpit, which resulted in significant energy savings as well as occupied equipment time, when compared to the CBP operations mode (OC1), in which the flaming operation was executed on the full surface of the slabs (useful and non-useful). In step 24, the geometries of the already flamed pieces were executed (the pieces were cut), by reading the QR code of the slab, followed by the pieces' QR code printing, operations followed by the customers in real-time. In step 25, the CPS controlled machines automatically performed functions such as anchoring holes and polishing tops, among others, from the QR parts interpretation, i.e. during the manufacturing process the parts informed the machines about what they must do, at a micro co-creation process level inside the CPS. Step 26 corresponds to the "Pieces Drying Execution" action, where once again the customers were asked about the realization of the value through the parts, which were already dry, the result being (R) in some cases and (-R) in cases where customers remotely considered the products to be inconsistent with their expectations. Since in this case (only one piece was recorded as non-quality), the process returned to step 22, moving at the second attempt to step 27, joining all the other cases where the Outcome had been (R) at the first attempt, without any dispute. With "Packing Execution" evidence (step 27), Phase 2 regarding the execution of the orders in the context of the OC3 operation was completed. In this Phase (2) there was huge activity by the CPS resources in all steps, from preparation of the raw materials up to product packaging. From the conclusion of step 27, in all five cases monitored, Outcomes (SO = A) had resulted, and the data collected related to the sequence of steps 19-27 of the service process in OC3 operations mode concluded successfully.

5.7 Operations Context OC3: Phase 3 (steps 28 to 36)

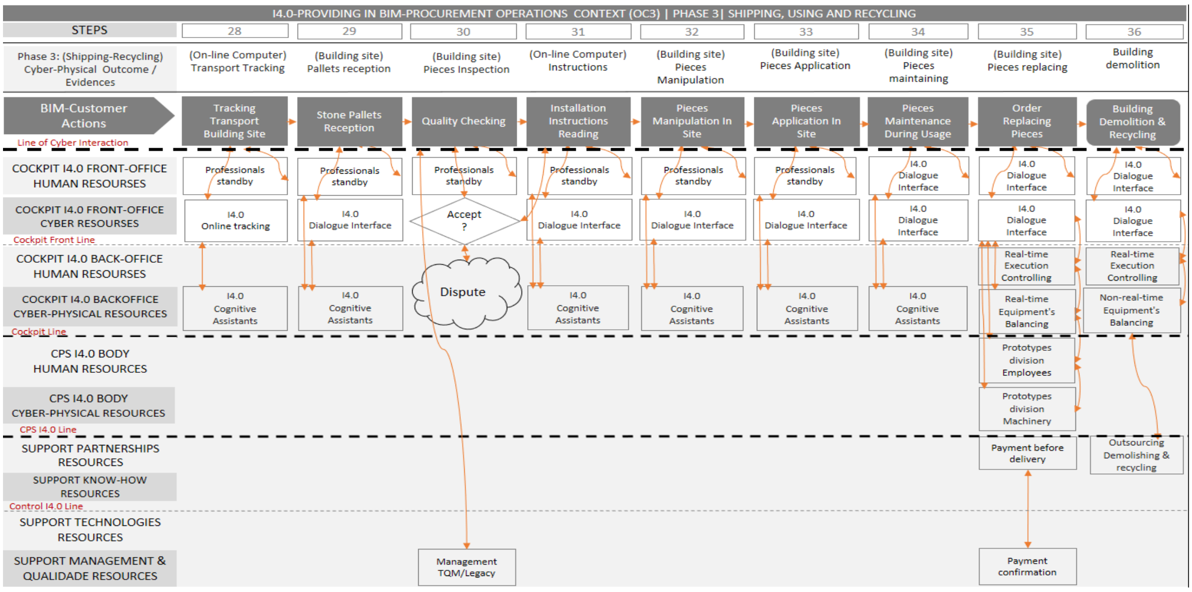

Figure 5.7: (I4.0-Providing in BIM-procurement) | Resources Activities, Access Rights and interaction Outcomes and Mapping | Phase 2 (steps 28-36)

The Phase 3 is related to “Shipping, Using & Recycling operations”, which for I4.0 means the ability to deliver products and participate in customer value co-creation until the building’s demolition (Figure 5-7). step 28 represents the "Transport Building Site" evidence, which meant the products were transported from the suppliers to the customers, which were on-line tracked in all cases by the BIM-Customers, after which they received the pallets (step 29), followed by of the most important steps of the process, quality checking in the "Quality Checking" action performed by the customer on-site (step 30). It is in step 30 that customers physically check the products, after which they report to the providers on the quality and value found in the delivered products, where the SO will be (R) if the customer considers the products are as expected and agreed, meaning the service proceeds to step 31, or on the contrary, SO will be (-R) if the customer considers that products have not been delivered with the expected value, which may even reach a legal dispute with the supplier. In the specific cases monitored in the context of the OC3 operation, all the BIM-Customers followed the orders’ execution remotely in real-time and made "on-line evaluations" in steps 21 and 26. This means that before the decisive step 30, there was already (virtual SO=R), and thus (SO = R) was also expected to occur in step 30 in CB3. It was in this context that the physical products delivered to customers were checked and according to the customers whether they were delivered as agreed, and so the service process moved to the "Installation Instructions Reading" (step 31) action, where the Cockpit resources were placed at the BIM-Customer's disposal once again for any clarification, as well as for the subsequent steps 32 and 33, regarding the handling and application of products on site. Thus, we have reached step 34, which represents the use of the products by the Customer, a situation that will occur during the next decades. However, during the period of use, the customer may request digital support from the BIM-Operator regarding product maintenance or parts replacement (steps 35, 35 and 36), (Figure C.9, Appendix C), related to the "Building site Pieces maintaining" actions," Building site Pieces replacing" and “Building demolition and recycling". For the researcher and for the scope of this thesis, the data collection process ended in step 33, since from this stage, the time of each action does not coincide, for obvious reasons, with the time to accomplish this research. In step 36, corresponding to the "Building demolition and recycling" evidence, the service process in the I4.0-Providing in BIM-Procurement Context (OC3) is over. During steps 27-33 it was possible to collect data, a situation not possible after step 33, the “pieces application” action, giving a step Outcome in all the monitored cases of (SO = A). By applying the empiric framework in the context of I4.0-Providing in BIM-Procurement (OC3), it was possible to map the full-service process

6. Conclusions and future work

In this research, an empirical framework was conceptualized, from the Service Science perspective, keeping in mind that the Industry 4.0 has a high level of complexity, in terms of actors and interactions occurring simultaneously and globally. By applying this empirical framework to a sample Ornamental Stone companies, we found that in traditional mode of operations, these companies are not able to provide customized orders under BIM-Procurement, thus losing in Digital context (BIM) their main competitive advantages. From this discrepancy arises a threat. Moreover, it was found that in the BIM-Procurement market, if these companies shift their operations to Industry 4,0 mode, they probably can retain their main current competitive advantage of customizing their products. From this we may conclude that the Industry 4.0 operations, potentially eliminates the threat raised from the BIM Procurement. Although the proposed objectives have been broadly achieved, there were several difficulties to overcome during this research, which led to some limitations. The literature review revealed that the Service Science literature dealing with I4.0 is scarce and, even more so, the literature on I4.0 digital production applied to a traditional sector and studied from the perspective of this new scientific discipline, a situation that caused additional difficulty in the conceptualization of the empirical framework. Once overcome, this has also contributed to practice and theory. For future works, we may propose to apply a similar conceptual framework to evaluate the impact of I4 .0 on these companies' response to other threats resulting from BIM procurement in the Architecture and Engineering Supply Chain.

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